DESIGN CONCEPT OF KIJANG RESEARCH REACTOR FOR NEUTRON TRANSMUTATION DOPING OF 300 MM INGOTS

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ABSTRACT

Neutron transmutation doping will be one of the important utilization areas of the Kijang research reactor, which is currently under design. The reactor will serve for at least 50 years. As the diameter of a current NTD ingot is already large compared to the size of the reactor, unless a provision in the reactor design is specifically made for the irradiation of potential larger diameter ingots in the future, the lifetime sustainability of the NTD activity, if possible, may be difficult to achieve.

While 200 mm became the largest diameter of NTD wafers a few years ago, 300 mm is the majority nowadays in the silicon semiconductor market, and one of the world leading device companies recently invested in the construction of a 450 mm fabrication plant. The usual peak time of a wafer diameter has been around 12 years. Though the generation gap of a NTD wafer diameter has become longer as time has passed, we can foresee that NTD demand for 300 mm ingots will arise within 20 years if their NTD is possible. Our calculations show that the radial uniformity for the 300 mm ingot irradiation may be acceptable by wafer companies. However, the NTD for 450 mm ingots is judged as impractical.

The KJRR is designed to irradiate 6" and 200 mm ingots to accommodate the major demands in the current and near future markets. We suppose that a 6" irradiation facility will be modified into a 300 mm irradiation facility when the demand for a 300 mm NTD arises. As the demand for the 300 mm NTD increases, other 6" and 200 mm NTD facilities will be modified one by one. A minimization of the component replacement and long-lived radwaste and a facilitation of the replacement work for each modification are important factors along with a better performance of NTD facilities.

1. Introduction

During the past 40 years of commercial neutron transmutation doping (NTD), which commenced in 1973, the largest NTD ingot diameter was enlarged from 2" to 200 mm (for wafer diameters larger than or equal to 200 mm, we use millimeters instead of inches because the actual diameters are close to 200 mm or 300 mm). We found that a modification of the reactor to accommodate larger diameter ingots, if possible, has been difficult in many reactors. The larger the ingot diameter, the smaller the number of research reactors that can irradiate, and only a few research reactors are now serving the 200 mm NTD.

The NTD will be one of the important utilization areas of a new research reactor currently under design in Korea, which is temporarily named the Kijang research reactor (KJRR).

The reactor will serve for at least 50 years. For the lifetime sustainability of the NTD activity in the KJRR, we should predict how the NTD ingot diameter will vary in the future. B.J. Jun [1] predicted this, and his study is summarized here and in the next section.

Jun studied the past trends of diameter variation in the NTD and the major wafers, as well as predictions on the future of major wafer diameters. He then roughly predicted the future of NTD wafer diameters. Based on this study, we concluded that, unless the NTD is replaced by a new technology, demand for a 300 mm NTD will arise within 20 years from now. Research reactors capable of 300 mm NTD will then be in demand. The major silicon wafers were actively transited from 200 mm to 300 mm in 2000, and the industry has been preparing for the next leap to 450 mm wafers. We do not expect that the minority market of NTD wafers can create a new industry of any other wafer size between 200 and 300 mm or between 300 and 450 mm. Although 450 mm wafers for power device applications may be introduced a long time later, we do not expect NTD for their ingots.

Therefore, we decided to design the KJRR to be capable of an NTD of up to 300 mm in the future. Since preparing 300 mm irradiation facilities from the beginning was judged as ineffective, we provide 6” and 200 mm NTD facilities to accommodate the major demand in the current and near future market first, and allow future modifications of them up to 300 mm NTD facilities in the reactor design. Calculations to check the radial uniformity of the 300 mm ingot irradiation show that it may be acceptable by wafer companies.

2. Prediction of future NTD wafer diameter

The semiconductor industry has developed technologies to produce larger diameter silicon wafers to meet the rapidly increasing demand for silicon semiconductor devices and to reduce their production cost. NTD wafers share a minor portion in the silicon wafer market and their diameters have followed those of major wafers with some generation gap. To predict the variation of NTD wafer diameter in the future, we compared the past history of diameter enlargement for both NTD and major wafers, and predicted future major wafer diameters. The results of the study are summarized in Fig 1.

The solid lines in the figure were drawn by SEMATECH (Semiconductor Manufacturing Technology) [2] in 1997 to predict 300 mm and 450 mm wafer markets after then. The trend after 1977 was roughly modified as drawn by the thick dotted lines, based on a variation of the annual market share depending on the wafer diameter after 1996, which was presented by T. Sonderman [3] in 2011. Past periods of major NTD wafers in the figure were determined based on several reports relevant to NTD and experiences at HANARO, and future periods were roughly estimated to follow the variation of major wafer diameter with some generation gap.

300 mm wafers take up the majority of the current silicon semiconductor market, and one of world leading device companies recently invested in the construction of a 450 mm fabrication plant. The usual peak time of a wafer diameter has been around 12 years, but that of 300 mm seems to be longer. Ingots for the major wafers are grown through the Czochralski (CZ) method. An open report predicting the next-generation wafer beyond 450 mm has yet to be found. A technology breakthrough from the conventional CZ method may be needed for the next-generation wafers.

For the case of NTD wafers, 6” became the majority, and demand for 200 mm arose a few years ago. Next-generation NTD wafers will be 300 mm. The generation gap of an NTD wafer diameter has become longer as time has passed. S. Pizzini [4] mentioned that the diameter of the current polycrystalline ingot was less than 200 mm, and the high cost limits the diameter of ingots grown using a floating zone (FZ) method. As the FZ ingots share the majority of NTD ingots, his view may also be regarded as an explanation on the generation gap of NTD wafers. It seems that a relatively small share of power devices in the silicon semiconductor market may cause a delay in the investment of industry for the development of a larger diameter FZ wafer. We do not expect that the minority market of FZ wafers can create a new industry of any other wafer size in between 200 mm and 300 mm.

However, as demand for silicon power devices is also rapidly increasing for alternative electricity generation, automobiles running on electric motors, the effective use of electricity, etc., demand for magnetic CZ (MCZ) and FZ ingots will also increase. The silicon power device market will grow to a size sufficient to justify 300 mm MCZ and FZ ingot production. Unless the NTD is replaced by another technology, demand for a 300 mm NTD will immediately follow.

Based on the above analyses, we concluded that the NTD demand for 300 mm ingots will arise within 20 years if their NTD is possible. A long time after the transition of a CZ wafer to 450 mm, demand for 450 mm MCZ and FZ wafers may follow for power devices. However, we do not expect NTD for their ingots.

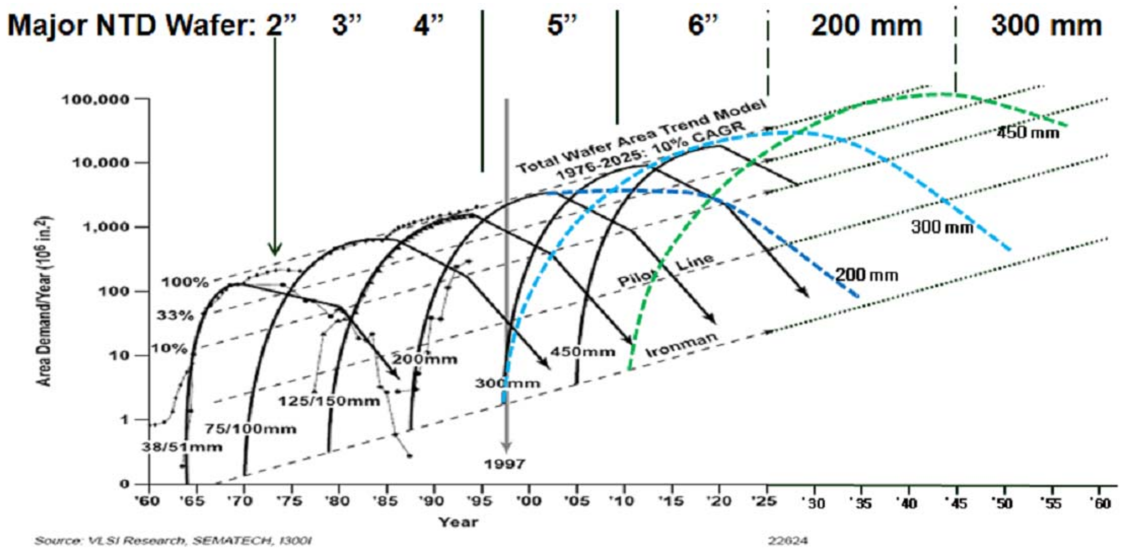

Fig 1. Prediction of wafer diameter trend

3. Design concept of KJRR for future 300 mm NTD

Fig 2 shows a plan view of the KJRR. The reflector region outside the core box is divided into eight segments. Each segment has its own replaceable grid plate. Six of the eight segments are assigned to five NTD holes and one fast neutron irradiation hole. The current design has two 6” NTD holes and three 200 mm NTD holes to accommodate the major demands in the current and near future markets. A fast neutron irradiation hole can be used for the irradiation of wafers of up to 200 mm. It can be converted into a NTD hole if the demand for wafer irradiation is not enough to justify the facility. The future modification of each segment for the irradiation of ingots or wafers of up to 300 mm is possible.

To check whether the radial uniformity of a 300 mm ingot irradiation will be acceptable, the radial distributions of the Si-30 reaction rate in the ingots are calculated for a core condition having all 300 mm NTD holes. As in the case of usual ingot irradiation, the highest reaction rate occurs at the ingot surface, the lowest is at the center, and their difference is a little less than 8%. This is sufficiently lower than the target that M. Yagi, et al. [5] assumed, which is 10%, to accommodate a deviation of the irradiation condition from the ideal symmetry.

However, as the actual NTD business specifies the radial resistivity variation (RRG), additional effects coming from the errors in resistivity measurements and initial resistivity distributions should be taken into account for the determination of RRG specification. Based on NTD experience at HANARO, we suppose that the 300 mm NTD will be feasible. However, the NTD for 450 mm ingots is judged impractical.

We suppose that a 6” irradiation facility will be modified to the 300 mm irradiation facility when the demand on the 300 mm NTD arises. As the demand for 300 mm NTD increases, other 6” and 200 mm NTD facilities will be modified one by one. Such a design with a provision to accommodate future larger diameter ingots reduces the current and near future NTD capacity. If the current market size and a trend shifting to a higher target resistivity are taken into account, however, the capacity will be large enough.

We expect that the segmentation of the reflector region facilitates the modification and is a way to minimize the component replacement. The minimization of long lived radwaste for the component replacement will be considered in the material selection.

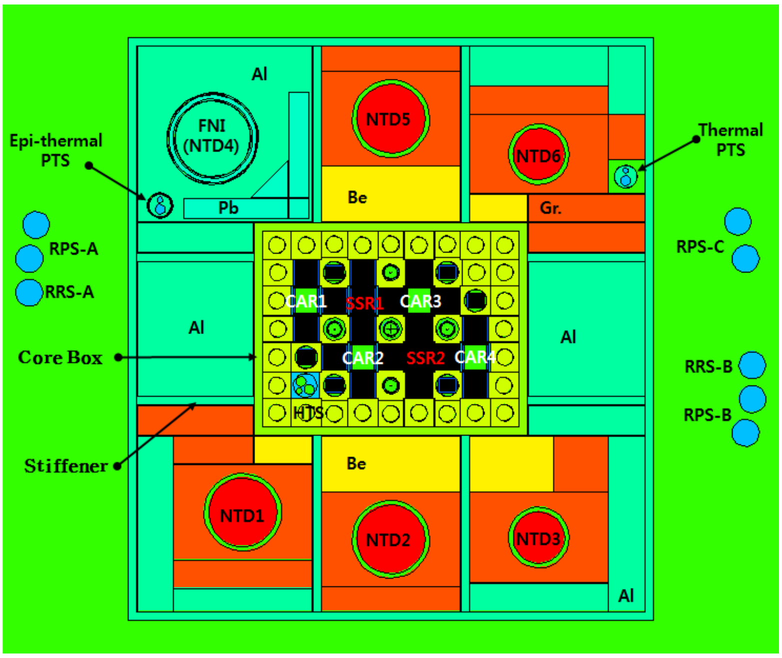

Fig 2. Plan view of KJRR core

4. Concluding remarks

We foresee that the RRG with a 300 mm NTD will be acceptable to wafer companies and that their demand will arise within 20 years from now. The KJRR will have initial 6” and 200 mm NTD facilities to accommodate the major demands in the current and near future markets, and will be modified to 300 mm NTD facilities one by one as the demand arises and then increases. The capability of research reactors to accommodate the 300 mm NTD will also be an important factor for the formulation of a 300 mm NTD market, because it is impossible without irradiation facilities. Actually, the capability of all research reactors in the world will be one of the important factors for the expansion of NTD demand, because the industry can expand its business only when a stable supply is possible.

Fig 1 assumes a constant rate of increase of 10%/y in the wafer market. The presentation of P. Gargini [6] is 9.5%/y until 2000 and 14%/y until 2009, after a drop in 2002, and more than 10%/y was then predicted after another drop in 2010. Therefore, the 10%/y assumed in Fig 1 seems reasonable. However, the trend of the NTD market has been quite different during the past 20 years after a big drop caused by an advance of gas doping technology in the early 1990s. In spite of this big drop, if the NTD demand increases in a similar way as the major semiconductor market, the current demand should be much more than the capability of current research reactors. The low growth would be due to the high cost compared to the chemical doping, but the limited capability of a reliable NTD in research reactors would also be a factor. We can also suppose that the limited capability of research reactors for a large diameter NTD could be a factor in the future for the slowing down of the diameter enlargement in the NTD. The ever increasing market size of the silicon semiconductor and the slow enlargement of the NTD wafer diameter indicate that the current irradiation facilities for 6” and 200 mm can be utilized for the long term in the future.

5. References

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